HARVESTING TECHNICAL NOTE

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Wire Rope End Connectors for Winch-assisted Machines

Summary

Wire rope terminations or end connectors are a critical component for securing the wire rope from a winch-assist machine to the felling machine in steep slope cable logging operations. Currently there are limited published testing data on the strength of various end connectors and no standardised tests for rejection or discard of end connectors. As the number of winch-assisted machines increases throughout New Zealand a high level of reliance has been placed on industry expertise and accepted practices. To improve the industry's understanding of wire rope end connectors and their suitability for winch-assisted machine applications, a survey of accepted cable logging experts was conducted. This report summarises the most common end connectors used and their advantages and disadvantages according to eight industry experts.

Hunter Harrill & Rien Visser, University of Canterbury, School of Forestry

INTRODUCTION

One type of winch-assisted harvesting system connects a feller buncher or shovel logging machine working on a slope to a mobile anchor that houses the winch, using wire rope. This system significantly extends the operating range of ground-based felling equipment, increases stability of the base machine on the slope itself, improves the ergonomics for the operator, as well as increasing harvesting system productivity (Visser and Stampfer 2015).

Wire rope terminations or end connectors are a critical component of the system for securing the wire rope from the winch-assist machine to the felling machine. There are many options for end connectors available. The end connector is never as strong as the rope itself, and some rope failures have occurred at or near the end connector. Considerable focus has been placed on the wire rope itself, including the tension on the rope. The load rating rule in the Approved Code of Practice for Safety and Health in Forest Operations (ACOP) states that the safe working load (SWL) must not exceed one-third of the rated breaking strength of the wire rope (MBIE 2012).

Guidance on wire rope inspection and rejection or discard criteria are provided in published Best Practice Guidelines (Competenz 2005, WorkSafeBC 2006) or in standards (ISO 4309). An interim Best Practice Guideline (BPG) for Cable Assisted Steep Slope Harvesting has been prepared by Hancock Forest Management NZ Ltd (HFMNZ, 2016) covering plant, ropes and rigging. However, no rules or guidance has been provided to aid contractors in end connector selection or inspection procedures. The ACOP does however require the system to be designed, tested and demonstrated to be safe, and certified by a chartered professional engineer.

Some end connectors have a rated strength, but it is important to note that the rating is for the fitting and not the connection. WorkSafeBC Occupational Health and Safety Regulations (Part 15 Rigging) provide some information on the strength of various connections. Cable logging specialist Brian Tuor has also carried out a limited series of strength tests on various eye splice options (Tuor, 2016). Given the limited information available, a high level of reliance is placed on industry expertise and accepted practices.

EXPERT SURVEY

This project surveyed eight accepted cable logging experts regarding wire rope end connectors specifically for use in winch-assisted harvesting systems. The survey consisted of two parts: evaluating the suitability of different types of end connectors; followed by discussing current inspection and maintenance procedures.

In the first part of the survey for each end connector type, participants were asked to:
(1) State whether or not the end connector type presented was suitable (i.e. yes, unsure or no) for winch-assisted harvesting operations;
(2) Rate the existing advantages and disadvantages associated with each end

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connector (i.e. strongly agree, somewhat agree, somewhat disagree, strongly disagree); and
(3) Add any comments they deemed pertinent. Survey participants chose not to respond to some questions.

In the second part of the survey, participants were asked which type of connector they preferred/recommended, the inspection interval for the type selected and what was their replacement strategy. Additionally, they were asked whether they agreed with the standard from the Best Practice Guidelines used to discard wire rope (Figure 1) and whether it should be applied to winch-assisted harvesting operations.

The following criteria indicate rope should be discarded:

- Severe surface wear and inter-strand nicking
- Broken wires near fittings
- Broken wires, when over a length of 8 diameters the total number of visible broken wires exceeds 10% of the total number of wires.
- Drum crushing
- Bird caging
- Kinking

Figure 1: Standard for discarding wire rope (Source: Best Practice Guidelines for Cable Logging, Competenz, 2005)

END CONNECTOR SUITABILITY

Spelter sockets

A spelter socket is a cast termination bonded to the wire rope using either molten metal or epoxy resin poured into the socket and hardened. WorkSafeBC Occupational Health and Safety Regulations (Part 15 Rigging) state that the spelter socket has 100% efficiency.

In the survey the majority of responses (five out of eight) said a spelter socket was a suitable connection for winch-assisted machines; while two said they were unsure and one said it was not.

The main advantage of the spelter socket compared to the other connector types is that it is the only type which has a strength efficiency that is estimated to be equivalent to the strength of the rope to which it is fitted and is rated as such. Most participants strongly agreed or somewhat agreed with these advantages. However, there was a 50/50 split in responses to whether the resin alternative to the white metal poured into the socket was just as strong and easy to install in the field. The reason being the level of cleaning and environmental conditions required by the manufacturer, as well as the training required, to successfully install the resin alternative.

The disadvantages associated with spelter sockets were agreed by all those surveyed: they have to be installed in the workshop (white metal), they are time consuming to make, the resin alternative takes several hours to cure, and they are expensive.

While one participant stated it was “the best connector on the market,” others who have used spelter sockets have had less favourable experiences due to early failure from corrosion or head damage during manufacturing. This type of connector is also less flexible, bulky, does not pull through sheaves (as required by some winch-assist systems) and is better suited for straight line and/or static rope applications.

Split wedge ferrules

A ferrule is a metal sleeve or collar, attached to the end of a wire rope by swaging (pressing), wedging, or babbitting. The wedge-type ferrule has spiral grooves on the inside designed to conform to the lay of the rope. The ferrule is driven down over the cut ends of the rope, then the strands are distributed each into its proper recess and the wedge is driven into the recess in the ferrule.

This type of end connector was perhaps the most controversial with four responses in the survey saying this was a suitable connection for winch-assisted machines; while three said it was not.

All participants agreed with the stated advantages: quickest installation of all types; common to loggers (i.e. used for chokers etc.); they are also light weight, easy to inspect and can be pulled through sheaves. Some participants have reported getting good service life when using 28mm diameter rope.

One of the disadvantages to which all participants agreed was that there is limited knowledge of their strength (i.e. variable results when tested and not published by manufacturers). The other disadvantage listed was that they are susceptible to frequent wire breaks. Two out of seven responses disagreed with this point however.

However, split wedge ferrules were never designed for being pulled through sheaves nor to be fitted to swaged or power swaged ropes. If not fitted correctly, overloading can occur on one strand and cause the rope to fail. Some participants have reported early failures for no apparent reason other than poor quality of manufacture.

Loggers' eye splice

Traditionally the most common end connector for wire rope, the loggers' eye splice has been used for many years to make an eye in the end of any piece of wire rope used in logging. The Cable Yarding Systems Handbook states that this type of end connector is less than 80% efficient if used without a thimble (WorkSafeBC 2006).

All responses (8) agreed that a loggers' eye splice was a suitable end connector for winch-assisted machines and was the only type of connector in the survey that had 100% approval from participants. The advantages associated with the loggers' eye splice are: that it's common to most loggers, can be installed in the field and is an ACOP approved practice; to which all the participants either strongly or somewhat agreed.

Disadvantages associated with the loggers' eye splice found less consensus among survey participants. Three out of seven responses somewhat disagreed that it was time consuming to install. One response somewhat disagreed that a logger needs good skills to balance strands, while two out of seven somewhat disagreed that it is not too strong (<80% rope strength). A recent study by Tuor (2016) found that the loggers' eye performed at 75-82% of the breaking strength of the rope.

Splicing takes time. A competent splicer with the correct tools can splice a loggers' eye in 15-20 minutes and a highly skilled splicer can complete one in 10 minutes. While it is commonly believed that it is important to balance strands; recent testing has shown that this may not be as critical as once thought. Tuor (2016) showed in his study that most eye splices failed in similar locations; namely at the last tuck (the base of the splice). Purposely unbalanced strands also failed at the same or similar tensions as well balanced splices.

The issue of eye deformation was strongly disagreed by two of the seven participants. A few participants noted that a disadvantage of this connector was its short lifespan relative to other types; and strongly disagreed that eye deformation was an issue because it is often taken out of service before it deforms (e.g. due to tucks being dislodged when pulling though dirt).

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Soft eye with pressed ferrule

Soft eyes with a pressed ferrule, are similar to a Loggers' eye (where the rope is folded over on itself) but has a hard connector (pressed ferrule) rather than a splice. The Cable Yarding Systems Handbook states that these eyes are 90-95% efficient (WorkSafeBC 2006).

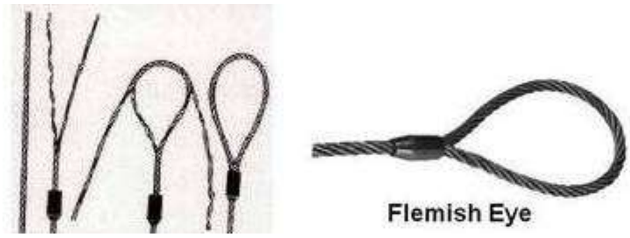
In the survey the soft eye with pressed ferrule reached less consensus over its suitability for winch-assisted operations. Three participants in the survey said it was suitable, and two said it was not, while one was unsure.

The advantage of the pressed ferrule on the soft eye is improved strength (90-95%) relative to splicing and the fact that they are approved by the ACOP if installed at an approved workshop. The HFMNZ Interim Best Practice Guidelines for Cable Assisted Steep Slope Harvesting 2016 (HFMNZ 2016) states that swaged eyes must be formed by an approved wire rope company. Most participants somewhat or strongly agreed with these advantages, and only one response somewhat disagreed with the advantage of high relative strength.

Regarding disadvantages of the soft eye with pressed ferrule, all participants strongly agreed that the main disadvantage is that the ferrule has to be installed at a certified workshop rather than the field. Most participants strongly or somewhat agreed that eye deformation without a thimble was a disadvantage but one participant strongly disagreed; due to the short service life similar to the loggers' eye.

While the pressed ferrule has increased strength compared to a soft eye that is spliced, their installation is really only practical on arrival direct from the manufacturer and/or if the machine is taken out of service. Furthermore, the hard connector (ferrule) creates a different mode of deterioration (i.e. broken wires near ferrule) and is actually a softer metal which, it was stated, users found to be highly susceptible to wear and cracking when dragging over the ground. One participant said that if it did fail due to cracking or wear, the concern was that the failure might be more sudden than with other types of connectors.

Flemish Eye Splice (aka Farmers' Eye or Married Eye Splice)



The Flemish or Farmer's eye is much like the soft eye with a pressed ferrule, only the rope is not folded over on itself. Rather it is split into two parts and relayed back together before the ferrule is pressed. WorkSafeBC Occupational Health and Safety Regulations (Part 15 Rigging) state that the Flemish eye is 92-95% efficient.

No survey participants suggested it was not suitable for winch-assisted operations, with four participants noting the Flemish eye was suitable and three said they were unsure. The main advantage of this connector over a soft eye with pressed ferrule is it's slightly higher strength (92-95%) from the way the rope is relayed back together. One advantage is that the eye can be tucked or clipped instead of pressing a ferrule, which is relatively fast and can be done in the field.

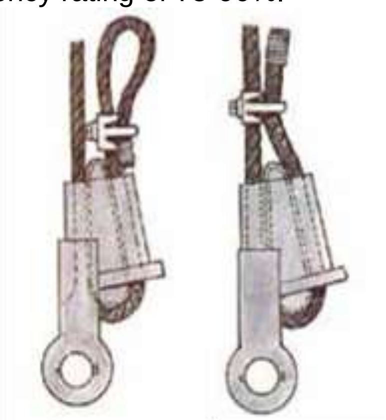
As with the soft eye with pressed ferrule the disadvantage of pressing a ferrule onto any eye is that it has to be done at a certified workshop. The disadvantage with tucking or clipping strands is that it's not as strong as using a ferrule and is quite variable (i.e. there is no published data from manufacturers stating the strength when clipped or tucked). All of the advantages and disadvantages discussed above were either

strongly agreed or somewhat agreed by participants.

While pressing a ferrule onto this type of eye improves its strength some participants said they were unsure of whether the specialised ferrules and dies for fitting were available in New Zealand. Additionally, common to other pressed ferrules they are quite susceptible to damage and the eye itself potentially susceptible to deformation without a thimble.

Wedged sockets

A wedged socket is a wire rope fitting where the rope end is secured by a wedge. According to WorkSafeBC Occupational Health and Safety Regulations (Part 15 Rigging) the wedged socket has efficiency rating of 75-90%.



In the survey half those surveyed (four respondents) thought that a wedged socket was a suitable type of end connector for winch-assisted operations; while one was unsure and one said it was not.

The main advantage of the wedged socket is its fast field installation (only one response disagreed with this statement). Another advantage is that some are strength rated (i.e. it has the SWL stamped on it); to which all the participants strongly or somewhat agreed. One participant noted that the SWL stamp was dependant on the manufacturer and some don't have it.

While wedged sockets are preferred by some due to their fast installation, some users are not comfortable using them in winch-assist operations due to the high vibrations and shock loading that occurs; which in other applications has caused them to work loose and/or fail.

The disadvantage of the wedged socket is that the tail of the rope protruding from the socket (which is usually clipped) gets easily damaged when pulled along or through the ground. However, one participant somewhat disagreed and said alternative methods of clipping could alleviate this issue. The other disadvantage is the variable strength of this type of connector; to which one participant somewhat disagreed. While their strength is significantly reduced if they are installed incorrectly, their strength also differs by manufacturer (e.g. 70-90%).

Although some participants have had issues with damage to the tail of the rope, others found it negligible and have suggested alternative types of pins and bolts for securing the tail that are better suited than conventional clipping methods. Furthermore, it was stated that some users prefer this connector due to its easy inspection, less slippage and that the rope remains in the state supplied by manufacturer (i.e. strands aren't deformed or spread) contributing to a relatively long service life.

Summary of Suitability

Table 1: Suitability of end connector for winch-assisted operations (NR= no response)

End Connector	Yes	No	Unsure	NR
Spelter sockets	5	1	2	0
Split wedge ferrules	4	3	0	1
Loggers' eye splice	8	0	0	0
Soft eye with pressed ferrule	3	2	1	2
Flemish eye	4	0	3	1
Wedged sockets	4	1	1	2

INSPECTION AND MAINTENANCE

Recommended end connector

When asked what type of connector they use (contractors) or recommend (manufacturers) most survey participants stated two end connectors in their response. The majority favoured a loggers' eye splice (Table 2).

Table 2: Number of recommendations for end connectors by type in the survey

End Connector	No.
Spelter sockets	2
Split wedge ferrules	2
Loggers' eye splice	6
Soft eye with pressed ferrule	1
Flemish eye	1
Wedged sockets	2

Half of the participants who recommended a loggers' eye splice, recommended it as a replacement end connector. In other words, they preferred a stronger end connector type, like a spelter socket or soft eye with pressed ferrule and once those wore out, they recommended replacing them with a loggers' eye which could be fitted in the field.

While the loggers' eye is versatile and common to loggers, there is still some preference towards other types of end connectors as noted by the varying responses; which could be due to machine type, past experience and cost or availability of various connectors, to name a few reasons.

Inspection interval

According to the HFMNZ Interim Best Practice Guidelines for Cable Assisted Steep Slope Harvesting (HFMNZ, 2016) a rigging register should be kept that identifies each component used in the winch-assisted system. This register should include each item's replacement or retest dates, and also include procedures for measuring and testing critical equipment and rules for replacement. For suitable wire rope care and maintenance, inspection and discard it recommends loggers refer to ISO 4309:2010 and that all wire rope and rigging must be visually checked daily.

Participants in the survey were asked to state a recommended inspection interval for the end connector. Every participant agreed that regardless of the end connector type used, a daily visual inspection should be undertaken. Additionally some said that the end connector should be inspected any time the operator had put it in a situation where it could have been damaged.

In addition to the daily visual inspection, some suggest that a more thorough inspection should be conducted weekly or monthly and perhaps a 3rd party inspection on an annual basis; but this varied depending on the type of connector used.

Broken wires near end connectors

The BPG for Cable Logging (Competenz, 2005) and the BC Cable Yarding Systems Handbook (WorkSafeBC, 2006) recommend replacement on finding a single broken wire near an end connector.

In this survey, participants were asked whether they agreed that the above standard should be applied to winch-assisted operations. Only one participant disagreed with this comment, stating that it would be satisfactory to have more than two broken wires where safety to people is not dependent on the connection. In all manned winch-assisted operations the operator is dependent on the connection; so this would only apply to fully remote controlled or teleoperated winch-assisted operations. One participant pointed out that there is one caveat with the above standard and how it is applied to cable yarding operations that isn't entirely clear the way that it is written. The standard is in fact written for "hard" connectors, such as pressed ferrules, wedged ferrules, pressed eyes, wedged sockets and spelter sockets. The standard addresses the common mode of failure for hard connectors called vibrational fatigue that is caused by the dissipation of energy in the cable against the hard

and inflexible junction of the wire rope and the end connector.

Replacement strategy

The final question to participants asked if, in addition to any damage criteria, they recommended a replacement strategy (i.e. hours or weeks of use) for the type of end connector they prefer. This question had the largest range of responses, with a commonly used statement "it depends." Due to the changing conditions and environment where winch-assisted machines are used and their non-cyclic nature, it was stated that some users prefer to apply damage criteria as their replacement strategy rather than a measure of time. One participant said that they took a conservative approach of refitting their wedged sockets monthly, to account for any unseen damage.

There was also some discussion about replacement strategy for the rope and whether this is separate from the end connectors used. One participant said the potential damage to the rope from such practices as bending around stumps/trees was more of a concern than wearing out the end connectors. Some companies and contractors are mandating a replacement of ropes after a specified hours of operation, whether the rope appears in good condition or not. However, this could be wasteful if the rope is still in good condition both externally and internally. Internal inspection of wire ropes is difficult and time consuming but non-destructive testing (NDT) is an option. One participant said they participated in a study funded by one forest management company (Hancock Forest Management NZ Ltd) where they had their wire rope tested non-destructively for internal damage (Byron, 2016).

SUMMARY

There are a variety of end connectors used in New Zealand winch-assisted harvesting operations. Each have their own advantages and disadvantages, based on the type of machine used and operator preference. While there are varying levels of consensus on the suitability of each type, it is clear that all participants agreed that the loggers' eye splice is a good option considering its advantages and disadvantages; both as an initial connector and as a replacement.

In terms of inspecting end connectors all participants agreed that regardless of end connector type, it should be visually inspected daily. Many suggested a more thorough inspection on a weekly or monthly basis, depending on type and perhaps a third party inspections annually if still in service. Most participants also agreed that a wire rope inspection standard (e.g. number of broken wires visible at the end connector) from the BPG for Cable Logging should be applicable to winch-assisted machines; but should be used for "hard" end connectors and not spliced eyes.

Due to the variable operating conditions encountered and various machine designs used in winch-assisted operations, a replacement strategy based on damage criteria rather than a specified number of hours of operation, may be preferable. There were also responses about the replacement strategy of the wire rope. Currently it appears that replacement strategies in place for both end connectors and wire rope are conservative due to uncertainty regarding end connector and wire rope life given the relatively new application of winch-assisted machines in New Zealand. A conservative approach is certainly prudent and not unwarranted, and it is recommended that more research be undertaken to add to the growing body of experience with these systems over time to determine what is most appropriate.

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- Mark Grimmer – Grimmer Contracting Ltd

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